

## Low-Frequency Scattering from Heterogeneous Sea Beds

Anatoliy N. Ivakin  
Applied Physics Laboratory, University of Washington  
1013 NE 40<sup>th</sup> Street  
Seattle, Washington 98105  
phone: (206) 616-4808, fax: (206) 543-6785, email: [ani@apl.washington.edu](mailto:ani@apl.washington.edu)

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### LONG-TERM GOALS

The long term scientific objective of this research is to improve our understanding the physics and mechanisms of acoustic bottom interaction and reverberation, including acoustic penetration, propagation, attenuation and scattering in elastic heterogeneous rough sea beds at low and mid frequencies.

### OBJECTIVES

The specific goal of this research is to develop a model of sea bed scattering due to volume heterogeneity consistent with existing propagation models and therefore to provide a self-consistent theoretical basis for improving and upgrading current bottom interaction codes (such as GABIM).

### APPROACH

In many practical cases, description of acoustic propagation and reverberation in marine environment requires knowledge of two acoustic characteristics of the bottom: reflection loss and scattering strength. At present, GABIM (Geophysical Acoustic Bottom Interaction Model [1]) developed at APL-UW represents the most general code used for predicting and analysis of these characteristics for a wide variety of sea bed types. Note however that there are also cases where these two characteristics are not adequate descriptors, and therefore *alternative* approaches and models are needed.

Due to general sedimentation and stratification processes, bottom geoacoustic parameters are usually functions of depth (this way these parameters are normally documented in various existing sediment databases and models [2]). The main motivating idea and ultimate goal for development of GABIM is to provide practical possibility for modeling and prediction concurrently both reflection and scattering from seafloors with *arbitrary* stratification, so that these depth-dependent functions taken from the sediment data bases could be directly used for such predictions.

Current version of GABIM is unable yet to fulfill above-mentioned ultimate goals. This project is aimed to significantly improve GABIM particularly by analysis and including most relevant published results of previous work: the elastic scattering model described in [3-5], a perturbation approach developed for scattering from continuous heterogeneity in layered fluid media [6-8], and discrete scattering work started in [9,10].

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## WORK COMPLETED

A part of completed effort is a contribution to improve GABIM. The volume scattering in elastic layers is by now the least developed part of this model. In particular, it uses the “windowing” approximation resulting in simplified formulas for bottom scattering strength in the cases of uniform bottom half-space (fluid or elastic basement) and a layered fluid sediment [3,6,11]. This significantly limits accuracy of these calculations, particularly at steep grazing angles (in near-specular directions). One of objectives in this project is to remove such limitations and study related effects.

In this research, a theoretical approach has been developed to take into account the “windowing effects” in a heterogeneous seafloor. At this stage of project, these effects were considered to modify models of volume scattering in an elastic half-space and in a fluid layer used in current version of GABIM [11]. The modified models were used in calculation of the bottom scattering strength [12] and are capable of improving two corresponding components of GABIM: the “sediment basement” component and the “sediment volume” component.

Another part of completed effort has included development of an *alternative* approach to describe scattering in a stratified marine environment which does not involve traditional acoustic characteristics: the bottom reflection loss and the bottom scattering strength. This approach significantly simplify accounting for the effect of stratification, using assumptions similar to described previously in [4] in a model of scattering from inhomogeneities in stratified sediments.

A preliminary version of this new modeling approach was used to demonstrate its compatibility with GABIM. This version also has a primary application to analysis of bottom scattering, but includes the case of discrete scatterers or inclusions [13]. This model can be considered as a supplement to GABIM, a recently published version of which treats only continuous heterogeneity of the sediment [11]. The new, modified model therefore is applicable to both types of scatterers, continuous and discrete, arbitrarily distributed in any part of stratified marine environment, seabed or water column.

## RESULTS

The main results obtained at this stage of the project are reported in [12-15]. An improvement to GABIM was to remove the windowing approximation used in the anisotropic volume scattering approach, see [11]. This requires a numerical integration, and calculations have shown [12] that this modification, having generally only a modest effect on backscattering predictions, significantly alters bistatic predictions near the specular direction.

An *alternative* approach is described in [13] to model scattering in a stratified marine environment. It makes it possible to significantly simplify accounting for the effect of stratification. The simplicity results from assumption that the spectrum of heterogeneity is a smooth enough function, allowing neglecting bistatic scattering effects by ignoring difference in wave vectors appearing in the stratified environment with both down-going and up-going waves. Importantly, calculation of low-frequency reverberation caused by volume heterogeneity in shallow water waveguide, if based on this approach, does not require using the equivalent bottom surface scattering strength. Therefore, the new approach is more general. Particularly, it can be applied to any part of marine environment, e.g. heterogeneous sea-water column or near-sea-surface layer, where compressibility may fluctuate significantly due to spatial variations of bubble concentration. Also, it can be used for description of volume scattering due to randomly distributed discrete fluctuations of various kind.

In [13-15], a simple physics-based model, GAMBID, is presented, which provides a relationship between the scattering intensity and statistical characteristics of randomly distributed, either in water column or in the seabed, arbitrary sized and shaped continuous or discrete objects. The scattering kernel is given by the local volume scattering coefficient, which is defined in two different ways. For continuous heterogeneity, it is defined by a spectral function of heterogeneity, and, for discrete scatterers, by their size/shape distributions. The model is applied to analysis of scattering from inclusions in stratified sand/mud sediments with shell inclusions, and model/data comparisons are presented.

## IMPACT/APPLICATIONS

This research is to develop an adequate theoretical basis for direct improving of GABIM, Geophysical Acoustic Bottom Interaction Model, the most general code used for predicting and analysis of the bottom scattering strength and reflection loss for a wide variety of sea bed types. GABIM is planned for submission to OAML (Oceanographic and Atmospheric Master Library) and has been already widely used in the applied research and development community. In particular, it is one of the primary tools used in the Ocean Bottom Characterization Initiative (OBCI). The model of discrete scattering from inclusions in arbitrary stratified sediment developed in this research can be applied to upgrade GABIM. Possible future developments of the model may include considering another important elastic boundary, heterogeneous sea-ice, and related applications in the Arctic environment.

## RELATED PROJECTS

This project is built on results of previous work funded by ONR-OA [4,5,8-10]. It is closely related with ongoing work to upgrade GABIM [11] developed at APL-UW, which is widely used in the applied research and development community.

## REFERENCES

1. K.Y. Moravan, M.L. Boyd, R.I. Odom, "GABIM Version 1.4", APL-UW, 16 April 2009.
2. E.L. Hamilton (1980), "Geoacoustic modeling of the sea floor", *J. Acoust. Soc. Am.*, **68**(5), 1313-1340.
3. A.N. Ivakin (1990), "Sound scattering by inhomogeneities of an elastic half-space", *Sov. Phys.-Acoust.*, **36**(4), 377-380.
4. D.R. Jackson and A.N. Ivakin (1998), "Scattering from elastic sea beds: First-order theory", *J. Acoust. Soc. Am.*, **103**(1), 336-345.
5. A.N. Ivakin and D.R. Jackson (1998), "Effects of shear elasticity on sea bed scattering: Numerical examples", *J. Acoust. Soc. Am.*, **103**(1), 346-354.
6. A.N. Ivakin (1986), "Sound scattering by random inhomogeneities of stratified ocean sediments", *Sov. Phys.-Acoust.*, **32**(6), 492-496.
7. Ivakin A.N. (1994), "Modelling of sound scattering by the sea floor", *J. de Physique IV*, pp.C5-1095--1098.
8. A.N. Ivakin (1998), "A unified approach to volume and roughness scattering", *J. Acoust. Soc. Am.*, **103**(2), 827-837.

9. Ivakin A.N. (2004), "Scattering from discrete inclusions in marine sediments", in, *Proc. Seventh European Conference on Underwater Acoustics (ECUA2004)*, Delft, The Netherlands, v. 1. pp.625-630.
10. A.N. Ivakin (2005), "High frequency scattering from sandy sediments: roughness vs discrete inclusions", in, *Boundary Influences in High Frequency Shallow Water Acoustics*, N.G. Pace and P. Blondel (Eds), University of Bath, UK, pp.185-192.
11. D.R. Jackson, R.I. Odom, M.L. Boyd, and A.N. Ivakin (2010), "A geoacoustic bottom interaction model (GABIM)", *J. Oceanic Eng.*, **35**(3), pp. 603-617.
12. A.N. Ivakin and D.R. Jackson (2011), "Wave scattering and interaction in elastic sea beds", *J. Acoust. Soc. Amer.*, **129**(4), Pt.2, p.2426 (A).
13. A.N. Ivakin (2011), "Remote characterization of random scatterer distributions in stratified marine environment", in, *Proc. 4th Internat. Conf. Underwater Acoustic Measurements: Technology and Results (UAM2011)*, J.S. Papadakis and L. Bjorno (Eds), pp. 1615-1622.
14. A.N. Ivakin (2011), "Geoacoustic modeling based on sediment particle analysis", *J. Acoust. Soc. Amer.*, **129**(4), Pt.2, p.2390 (A).
15. A.N. Ivakin (2010), "Scattering from inclusions in stratified marine sediments", *J. Acoust. Soc. Amer.*, **128**(4), Pt.2, p.2327 (A).

## PUBLICATIONS

- A.N. Ivakin (2011), "Remote characterization of random scatterer distributions in stratified marine environment", in, *Proc. 4th Internat. Conf. Underwater Acoustic Measurements: Technology and Results (UAM2011)*, J.S. Papadakis and L. Bjorno (Eds), pp. 1615-1622.
- A. N. Ivakin (2011), "Sound scattering from the ocean bottom: recent theoretical and experimental results", in, *Ocean Acoustics*, Proc. 13<sup>th</sup> L.M. Brekhovskikh's conference, Moscow: GEOS, pp.118-125.
- A.N. Ivakin and D.R. Jackson (2011), "Wave scattering and interaction in elastic sea beds", *J. Acoust. Soc. Amer.*, **129**(4), Pt.2, p.2426 (A).
- A.N. Ivakin (2011), "Modeling for remote acoustic characterization of gas hydrates", *J. Acoust. Soc. Amer.*, **129**(4), Pt.2, p.2653 (A).
- A.N. Ivakin (2011), "Geoacoustic modeling based on sediment particle analysis", *J. Acoust. Soc. Amer.*, **129**(4), Pt.2, p.2390 (A).
- A. N. Ivakin (2012), "Sound scattering from the seafloor: Results of recent theoretical and experimental research", *Acoustical physics*, **58**, 151-155. [published, referred]
- A.N. Ivakin (2012), "Modeling of acoustic backscatter for remote detection and characterization of oil and gas in marine environment", in, *Proc. 11th European Conference on Underwater Acoustics (ECUA2012)*, Edinburg, UK, 2-6 July 2012, pp.1202-1209.
- D.R. Jackson, B.T. Hefner, A.N. Ivakin, G. Wendelboe (1912), "Seafloor characterisation using physics-based inversion of multibeam sonar data", in, *Proc. 11th European Conference on Underwater Acoustics (ECUA2012)*, Edinburg, UK, 2-6 July 2012, pp.1571-1576.
- D.R. Jackson, A.N. Ivakin (1912), "Modeling issues in scattering by layered seabeds", in, *Proc. 11th European Conference on Underwater Acoustics (ECUA2012)*, Edinburg, UK, 2-6 July 2012, pp.1180-1187.

- R.E. Moritz, A.N. Ivakin (2012), “Retrieving sea-ice thickness from ULS echoes: Methods and data analysis”, in, *Proc. 11th European Conference on Underwater Acoustics (ECUA2012)*, Edinburg, UK, 2-6 July 2012, pp.1535-1542.
- A.N. Ivakin, A.B. Zolotukhin (2012), “Energy exploration and the environment in the Arctic”, in, *Second Skolkovo Tech Research Center Proposers Conference Abstracts*, Skolkovo Tech, Moscow Region, Russia, 9-10 July 2012, p.35.